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New general engineering geological map of Slovenia

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Abstract

The new lithostratigraphic map of the entire Slovenia (in the scale of 1:250000) created by using the GIS method enabled the production of its derivative – engineering geological map (EG map). The goal of creating this map was to define the general engineering geological characteristics of rocks and soils that will be used for the general review of engineering geological conditions in Slovenia. The map also enables the planing of general interventions in Slovenia. The EG map was created by using the GIS method for merging the lithology units of Slovenia according to EG characteristics on three levels. The first one is the basic separation into soils, soft rocks and rocks. The second level is a more detailed separation on the basis of their origin and the third one on the basis of the composition, rock strength and particle size ranges. The first basic GIS layer determined the EG units merged with the database, giving the spatial and description data for each unit.

The basic data for each unit was stored in the GIS-database (serial number, the connection to the lithology unit, the name, short description, comprehensive description, the occurrence in Slovenia). The EG units were also stored in the database (the description of EG units, geotechnical characteristics, the foundation conditions, seismic characteristics). The map was further detailed by the creation of informational layers derived from the map. In this manner the map of rock strength, the map of possible land sliding, the map of weathering cover thickness estimation and the erosion map were produced. The GIS modelling method was used for the creation of these maps. For example, the map of possible land sliding was created regarding these informational layers: lithology structure, the thickness of weathering cover, the slope inclination and the hydrogeological conditions.

Kratka vsebina

Na novo izdelana geološka karta v GIS-u merila 1 : 250.000 teritorija Slovenije je omogočila tudi izdelavo izpeljanke – inženirskogeološke karte. Cilj izdelave inženirskogeološke karte je opredeliti splošne inženirskogeološke lastnosti hribin in zemljin, ki bodo služili za generalni uvid v inženirskogeološke razmere Slovenije. Poleg tega inženirskogeološka karta omogoča planiranje posegov v prostor v državnem merilu.

Inženirskogeološka karta je bila izdelana tako, da so bile litološke enote Slovenije s pomočjo GIS tehnologije med seboj združene po inženirskogeoloških lastnostih v treh nivojih. Prvi nivo je osnovna delitev v zemljine, polhribine in hribine, drugi že detajlnejši po načinu nastanka ter tretji po sestavi, trdnosti in zrnavosti. Tako so bile na osnovnem informacijskem sloju opredeljene inženirskogeološke enote, kateremu je bila pridružena baza podatkov, ki je za posamezno enoto podajala prostorske in opisne podatke.

Za vsako enoto so tako bili v GIS-bazi shranjeni osnovni podatki (zaporedna številka, povezava na litološko enoto, ime, kratek opis obsežnejši opis, razširjanje v Sloveniji) in inženirskogeološke lastnosti (opis inženirskogeoloških lastnosti, geotehnične lastnosti, pogoji temeljenja, seizmične lastnosti). Pri nadaljevanju dela je bila inženirskogeološka karta še detajlirana z izdelavo iz nje izpeljanih informacijskih slojev, ki so izrazili eno izmed pomembnih inženirskogeoloških značilnosti. Tako so nastali še karta trdnosti kamnin, karta podvrženosti plazenju, karta ocene debeline preperinskega pokrova in karta seizmičnih lastnosti tal. Za izdelavo teh kart je bilo uporabljeno GIS modeliranje. Tako je npr. karta podvrženosti plazenju nastala z upoštevanjem naslednjih informacijskih slojev: litološke zgradbe, debelina preperine, nagib terena in hidrogeološke razmere.

Introduction

The production of the new lithostratigraphic map (Buser, 1999) in the scale of 1:250,000, dividing in great detail the Slovenian territory according to the lithological characteristic of its structure, also enabled the creation of an engineering geological map of the same scale as its upgrade. To this purpose, the lithological units were merged with regard to their relative engineering geological properties. In the preparation of the engineering geological map, two criteria were primarily used. The first one was the classification of the material composing the Slovenian territory into soils, soft rocks and rocks. The geomechanical characteristics of rock and its sensitivity to weathering greatly depends on its maturity and lithification. The second decisive criterion was the content of small clay fraction in rock structure. Rocks composed of clay as well as silt fraction are more susceptible to landsliding and other destructive processes.

In joining the rocks according to their similar engineering geological properties, it was necessary to take into account that the Slovenian territory is geologically very complex. A single lithologically homogenous rock is very rare. Most frequently, there is an alternation of different lithological variants, or the prevailing rock comes with inclusions, layers or veins of other rocks. This is the reason why it is not always possible to stick to the classifications set up in the extensive literature.

The purpose of engineering geology as a practical science is to offer an engineering geological map as an answer to a certain problem appearing in spatial development or in the preservation of the environment connected with such activities. The general engineering geological map, like this one, thus only presents the generalised engineering geological characteristics of an area. However, general engineering geological maps can also be produced for specific purposes. In such a case, rocks are categorised according to their engineering geological properties that are important for obtaining the answer sought. This part of the task, is the second step in the production of the engineering geological map of Slovenia.

The processing of engineering geological data in the GIS environment

In the lithostratigraphic map, the 112 lithological units are represented by 4651 separated polygons. On the basis of the key which is described in more detail in the following chapter, each polygon was reclassified into new classes, indicating the engineering geological properties of rocks. The first part of the table (for soils), which was used for the reclassification from the lithostratigraphic map to the engineering geological map, is shown below:

Tab.1. Reclassification of the lithostratigraphic map to the engineering geological map

ACAD_ ELEV	ID no.	EG mark	Decimal Class.	DESCRIPTION
2	1	ZEM-R	111	clay (Quaternary)
13	1	ZEM-R	111	brown clay, terra rossa and loam (Quaternary and Pliocene)
14	1	ZEM-R	111	clay and weathered material with chert (Quaternary and Pliocene)
7	2	ZEM-R	112	clay, peat (marsh sediments - Quaternary)
8	2	ZEM-R	112	clay, silt and weathered peat (marsh and lake sediments – Quaternary)
9	2	ZEM-R	112	clayey silt (continental and marsh loess – Quaternary)
1	3	ZEM-R	113	alluvium (pebble, sand, silt and clay – Quaternary)
10	3	ZEM-R	113	fluvial loose sediments in terraces (pebble, sand, silt and clay – Quaternary)0
5	4	ZEM-P	121	diluvium (mainly clay with pieces of various rocks – Quaternary)
3	5	ZEM-P	122	talus (Quaternary)
4	6	ZEM-P	123	alluvial fan (gravel, pebble and silt – Quaternary)
12	6	ZEM-P	123	moraines – tuff (Quaternary – Pleistocene)
15	7	ZEM-K	131	clay, clayey silt with pebbles of flint and silicate rocks (Pliocene and Pleistocene)
20	7	ZEM-K	131	clay, silt and sand (Pliocene)
19	8	ZEM-K	132	sandy marl, clay and small pebbles (Lower Pliocene)
21	8	ZEM-K	132	sand and clay (Upper Miocene and Lower Pliocene)
22	8	ZEM-K	132	clayey marl, sand, pebble and clay (Upper Miocene)
16	9	ZEM-K	133	flint pebble, sand and silt (Upper Pliocene)
18	9	ZEM-K	133	pebble, and sandy clay (Middle Pliocene)
6	10	ZEM-A	141	mine tailings (anthropogenic recent sediments)

Tab. 2. Frequency of appearance and the area that it covers in kilometres

EG – mark	Description	Frequency of appearance	Area (km^2)
ZEM-R	soil (alluvium)	533	3696
ZEM-P	soil (on slope)	305	601
ZEM-K	soil (rocks with soil properties)	203	1113
ZEM-A	soil (anthopogenic)	4	28
POL	soft rocks	303	1559
KLA	clastic rocks	782	2991
KAR	carbonate rocks	2093	8920
MET	metamorphic rocks	158	759
MAG	magmatic rocks	232	694

Each lithostratigraphic element, numbered by ACAD_ELEV, corresponds to a ID number according to the engineering geological map. In addition, the engineering geological unit obtained in this way is classified into the basic engineering geological class with regard to its engineering geological properties, i.e. obtains the appropriate decimal mark. Thus, in the table above, the engineering geological mark (EG mark) ZEM-R, means an engineering geological unit classified among soils (ZEM), alluvium deposits (mark R). The decimal classification 111, which has three levels, indicates that the engineering geological unit belongs among soils (first number), alluvium deposits (second number) and that it predominantly consists of clay (third number). The lithostratigraphic elements are divided into 9 classes with regard to their basic engineering geological characteristics. The following table gives the incidence for each class and the surface that it covers in kilometres.

The brief description of the logical structure serving as the basis for the preparation of an engineering geological map

The basic engineering geological map determining the general engineering geological characteristic of the Slovenian territory is based on the key below. The key distinguishes between soils, soft rocks and rock (level 1).

The soils are further divided into alluvium soils (fluvial and stream alluvia), slope soils (diluvia, proluvia, slope alluvial fans and talus), rocks with soil properties and anthropogenic soils (man-made fills of large surfaces). Soft rocks have already been partially lithified, but their humidity, firmness and other geomechanical properties are still too low for them to be classified among rocks. Thus, they represent a class of their own. Rocks are divided into clastic, carbonate, metamorphic and magmatic rocks (level 2).

At the third level (level 3), the material is divided into three groups: geotechnically least appropriate, medium-appropriate heterogeneous material and geotechnically most resistant material. When there is an alternation of geotechnically different materials, the criterion for classification is the prevailing material.

Each lithological unit connected with ID AcadElev according to the original table is then classified by its engineering geological properties into the engineering geological class defined by the indication of ID no. (the serial number of the engineering geological group), engineering geological mark (generally classifying the material according to its engineering geological properties) and Dec.Cl. (decimal division of materials into classes), like it is shown above.

Description of engineering geological units

The engineering geological map comes with general and detailed descriptions of the engineering geological characteristics. The general description of an engineering geological unit contains the following information:

A. NAME OF UNIT
B. LITHOLOGICAL AND EG DESCRIPTION OF THE ROCK
C. INCIDENCE IN SLOVENIA
D. CHARACTERISTIC TERRAIN MORPHOLOGY
E. DESCRIPTION OF THE STRUCTURAL DISCONTINUITIES OF THE ROCK

Tab. 3. The logical structure and the basis for the preparation of an engineering geological map

BASIC CLASSIFICATION

Level 1	Level 2	Level 3	EG mark	Dec.Cl.
SOILS (ZEM)	ALLUVIUM SOILS (and terrace sed.)	predominantly clayey soils	ZEM-R	111
		marsh, lake soils (clay, silt, peat)	ZEM-R	112
		alternation of different soils (pebble, sand, clay, etc.)	ZEM-R	113
		pebble and sandy pebble	ZEM-R	114
	SLOPE SOILS	clayey – diluvial, proluvial	ZEM-P	121
		gravely (with a clayey component)	ZEM-P	122
		gravely (predominantly thick fraction), moraines	ZEM-P	123
	ROCKS WITH SOIL PROP.	clayey	ZEM-K	131
		alternation of fine and coarse grain soils	ZEM-K	132
		pebbly	ZEM-K	133
	ANTHROPO-GENIC SOILS	mine trailings – gangues	ZEM-A	141
		mounds, soil barriers	ZEM-A	142
		deposits of urban and other wastes	ZEM-A	143
SOFT ROCKS		clayey, marly	POL	201
		clayey, marly and limestone	POL	202
		alternation of different materials (marl, sand, sandstone, conglomerate pebble, clay etc.)	POL	203
		conglomerate with possible soil inclusions	POL	205
ROCKS	CLASTIC ROCKS	(slaty) claystones with inclusions of other rocks	KLA	301
		marl and sandstone (flysch) with inclusions of other rocks	KLA	302
		sandstones and conglomerates with inclusions of other rocks	KLA	303
	CARBONATES	stratified and cliff limestones	KAR	401
		flat limestones	KAR	402
		limestones and dolomites	KAR	403
		dolomites	KAR	404
		limestones with marls	KAR	405
		limestones with inclusions of other rocks	KAR	406
		limestone conglomerates and breccia	KAR	407
	METAMORPHIC ROCK	phyllites, schists and slate	MET	501
		amphibolite and gneiss	MET	502
	MAGMATIC ROCK	diabase and other magmatic rocks with tuff	MAG	601
		amphibolites, serpentinites, diaphthorites	MAG	602
		tonalite, dacite, granodiorite	MAG	603

F. WEATHERING
G. WEATHERING COVER
H. EROSION
I. TERRAIN STABILITY AND LANDSLIDE INCIDENCE
J. SUSCEPTIBILITY TO ROCKFALLS
K. HYDROGEOLOGICAL PROPERTIES
L. SEISMIC SENSITIVITY
M. CONSTRUCTION CONDITIONS

A detailed description of each engineering geological unit was also made. Part of the description for soils is given below as an example:

Soils – alluvium soils (ZEM-R)
- 111 predominantly clayey soils
- 112 marsh, lake soils (clay, silt, peat)
- 113 alternation of different soils (pebble, sand, clay, etc.)
- 114 pebble and sandy pebble

According to the EG classification, fluvial and stream alluvia are divided into four sub-units (111, 112, 113 and 114). The first includes sediments (of Quaternary or Pliocene age), mostly composed of clayey soils (111). It also includes terra rossa. They can be found in the basins of karst sinkholes, primarily in Dolenjska, at the margins of large basins, like the Drava and Mura basins, and in smaller patches also elsewhere in Slovenia. They form a flat or slightly undulating terrain. They are susceptible to erosion along waterways. They are impermeable to water and act as an insulator. Interference with them may be problematic due to their low bearing capacity and possible large differential subsidence. Deep slope and embankments require protective measures in order to ensure the stability of the excavation walls. If they

are thick, they are appropriate for waste deposits. In case of an earthquake, a considerable increase in the seismic impact is expected.

Upgrading of the engineering geological map

The next step in the preparation of the general assessment of the engineering geological properties of rock in the Slovenian territory was the creation of maps showing certain important engineering geological characteristics:

Thus, the following maps were derived from the basic engineering geological map:

- the map of rock classification according to rock strength properties,
- the map of rock classification according to stability or susceptibility to landsliding,
- the map with the assessment of the weathering cover thickness.

In the preparation of the above maps by means of GIS, other information layers were also used. Thus, the map of stability also took into account the following as input information layers:

- lithology
- the map with the assessment of the weathering cover thickness
- the hydrogeological map of Slovenia
- DEM (Digital Elevation Model)

Tab. 4. Weighting factors of information layers

Influence factor	Percent of influence
lithology	20%
weathering cover	40%
slope inclination	30%
hydrogeology	10%

We determined the influence factors for each information layer. For the stability map, they were the following:

The basic input data for the production of the derived maps were obtained by making an assessment of a certain engineering geological property for each lithostratigraphic unit, like shown in the following table and the keys attached:

Derived maps from the basic engineering geological map are shown below:

Conclusion

The general engineering geological map in the scale of 1:250,000 was first used in searching for the location for the low radioactive waste deposit in Slovenia. Otherwise, it is not especially significant in construction and other local spatial development, however, it becomes important in spatial planning in a wider area and in understanding the engineering geological characteristics of the Slovenian territory.

Tab. 5. Assessment of an engineering geological properties

Acad Elev.	ID no.	EG mark	Dec. class.	DESCRIPTION	Weathering cover – soil	Erosion	Rock strength	Stability/ lithology
2	1	ZEM-R	111	clay (Quaternary)	1	1	2	2
13	1	ZEM-R	111	brown clay, terra rossa and loam (Quaternary and Pliocene)	1	1	2	2
14	1	ZEM-R	111	clay and weathered material with chert (Quaternary and Pliocene)	1	1	2	1
7	2	ZEM-R	112	clay, peat (marsh sediments – Quaternary)	1	1	2	1
8	2	ZEM-R	112	clay, silt and weathered peat (marsh and lake sediments – Quaternary)	1	1	2	1
9	2	ZEM-R	112	clayey silt (continental and marsh loess – Quaternary)	1	1	2	2
1	3	ZEM-R	113	alluvium (pebble, sand, silt and clay – Quaternary)	1	1	1	3
10	3	ZEM-R	113	fluvial loose sediments in terraces (pebble, sand, silt and clay – Quaternary)	2	1	1	3

Weathering cover – soil (LEGEND)	
1	Soil, clayey, silty with weathered material properties
2	Soil, pebbly (gravely) with weathered material properties
3	Very thick and thick weathering cover
4	Weathering cover of medium thickness
5	Thin weathering cover

Erosion (LEGEND)	
1	highly erodable rocks
2	moderately erodable rocks
3	poorly erodable rocks

Rock strength properties (LEGEND)	
1	cohesionless soils
2	cohesive soils
3	soft rocks
4	soft and medium-hard rocks
5	hard
6	very hard rocks

Stability (LEGEND)	
1	very high possibility of the landslide appearance
2	high possibility of the landslide appearance
3	medium possibility of thelandslide appearance
4	moderate possibility of the landslide appearance
5	very low possibility of the landslide appearance

Fig.1. Weathering cover map

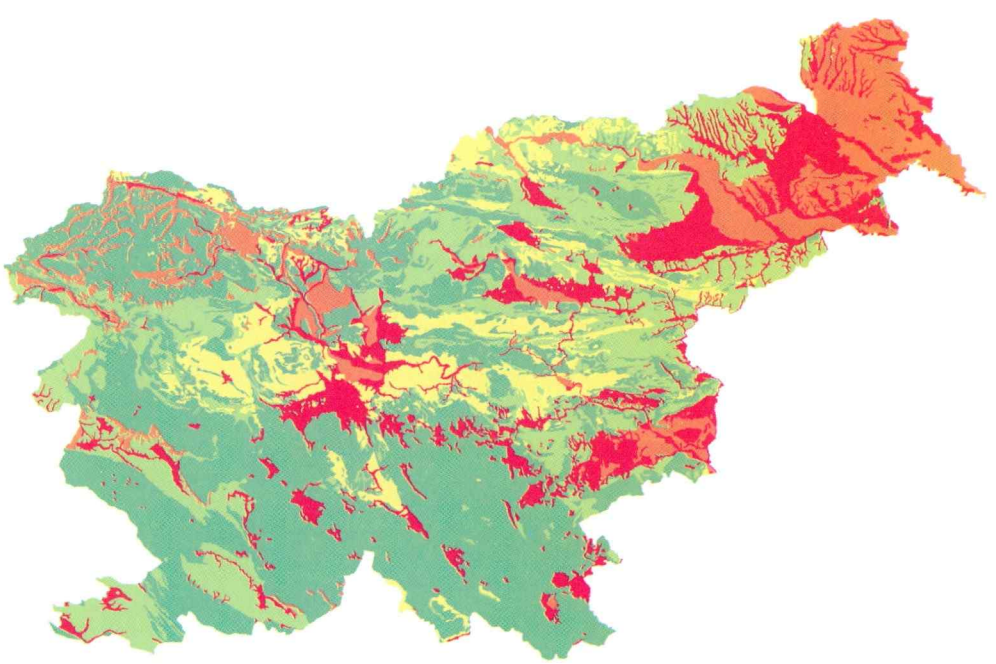


Fig.2. Erosion map

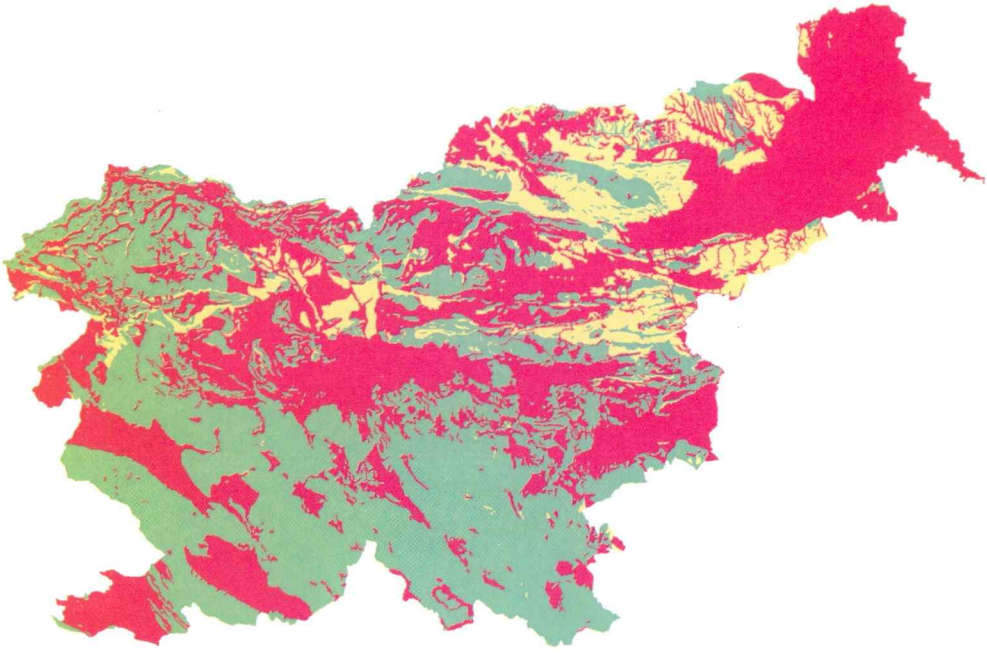


Fig.3. Rock strength properties map

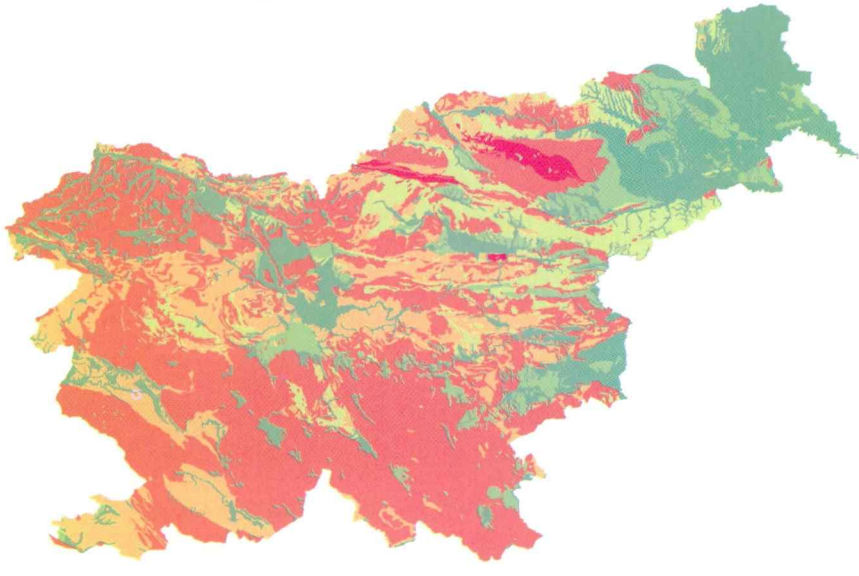
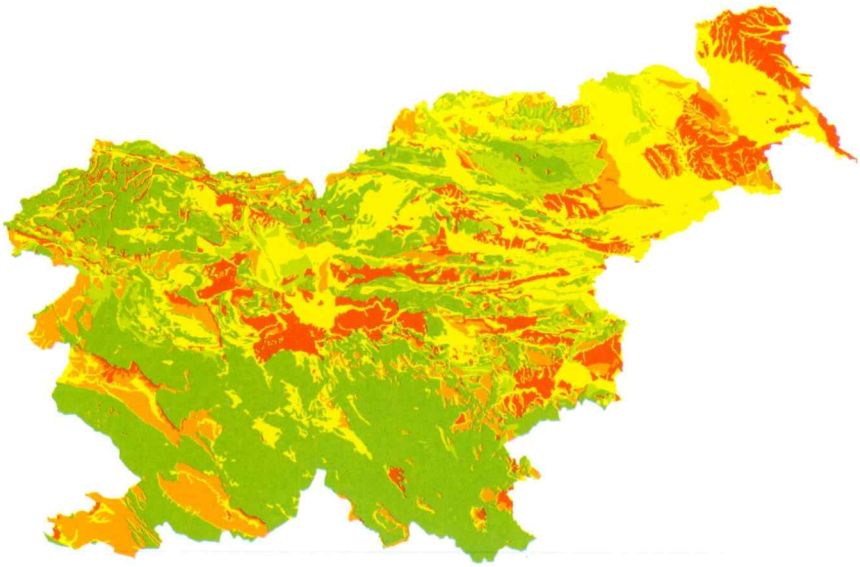


Fig.4. Stability map



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